

Figure 1

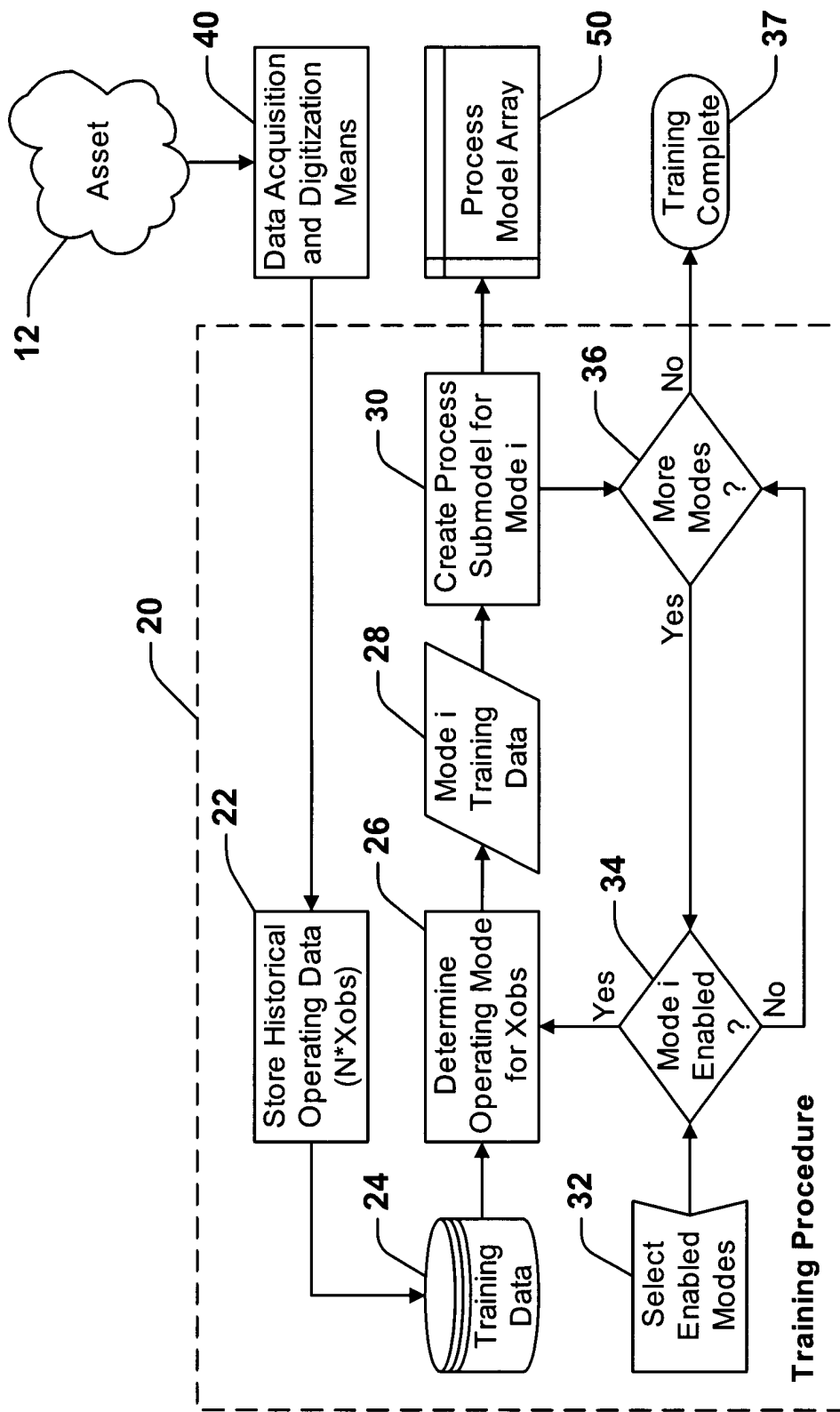


Figure 2

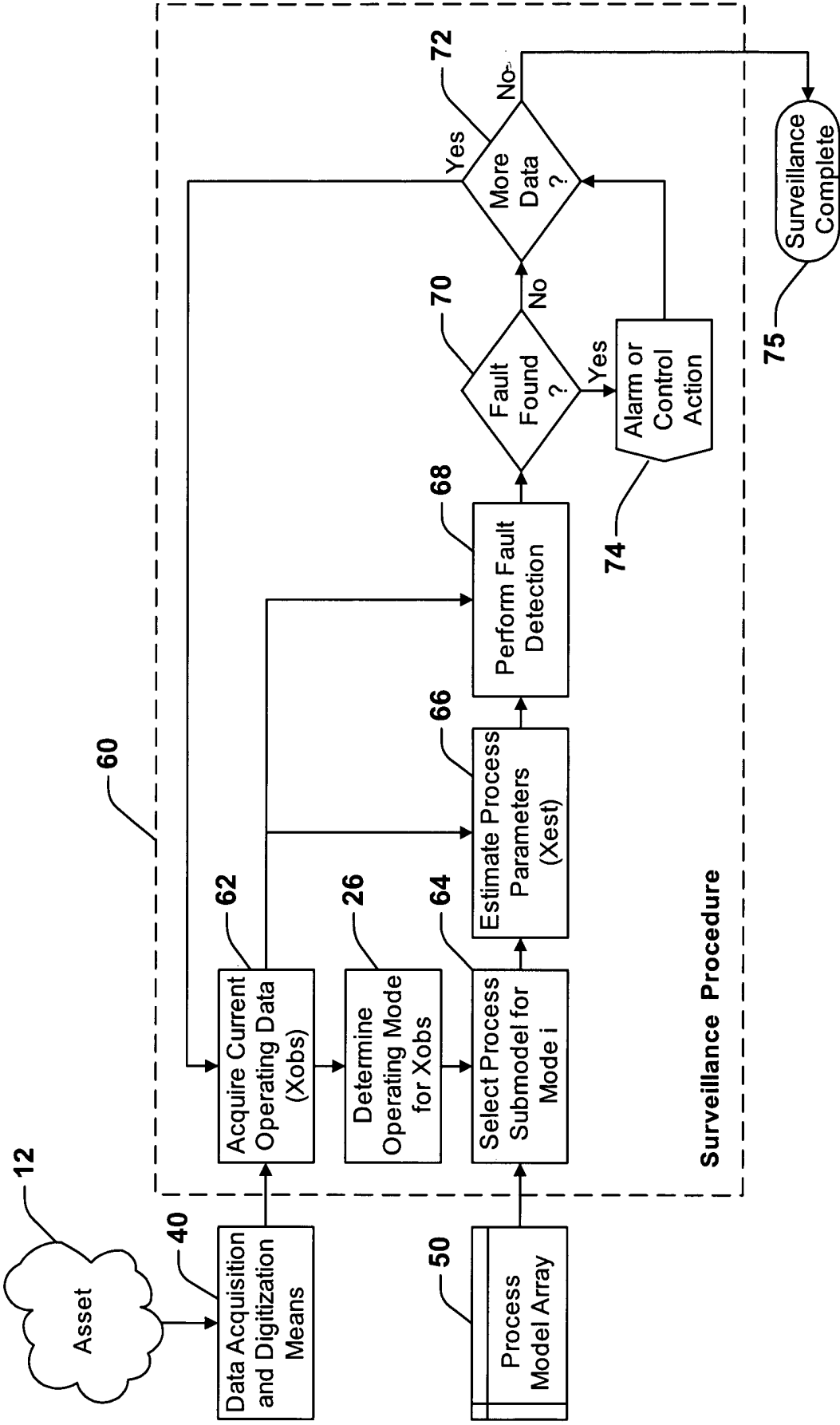


Figure 3

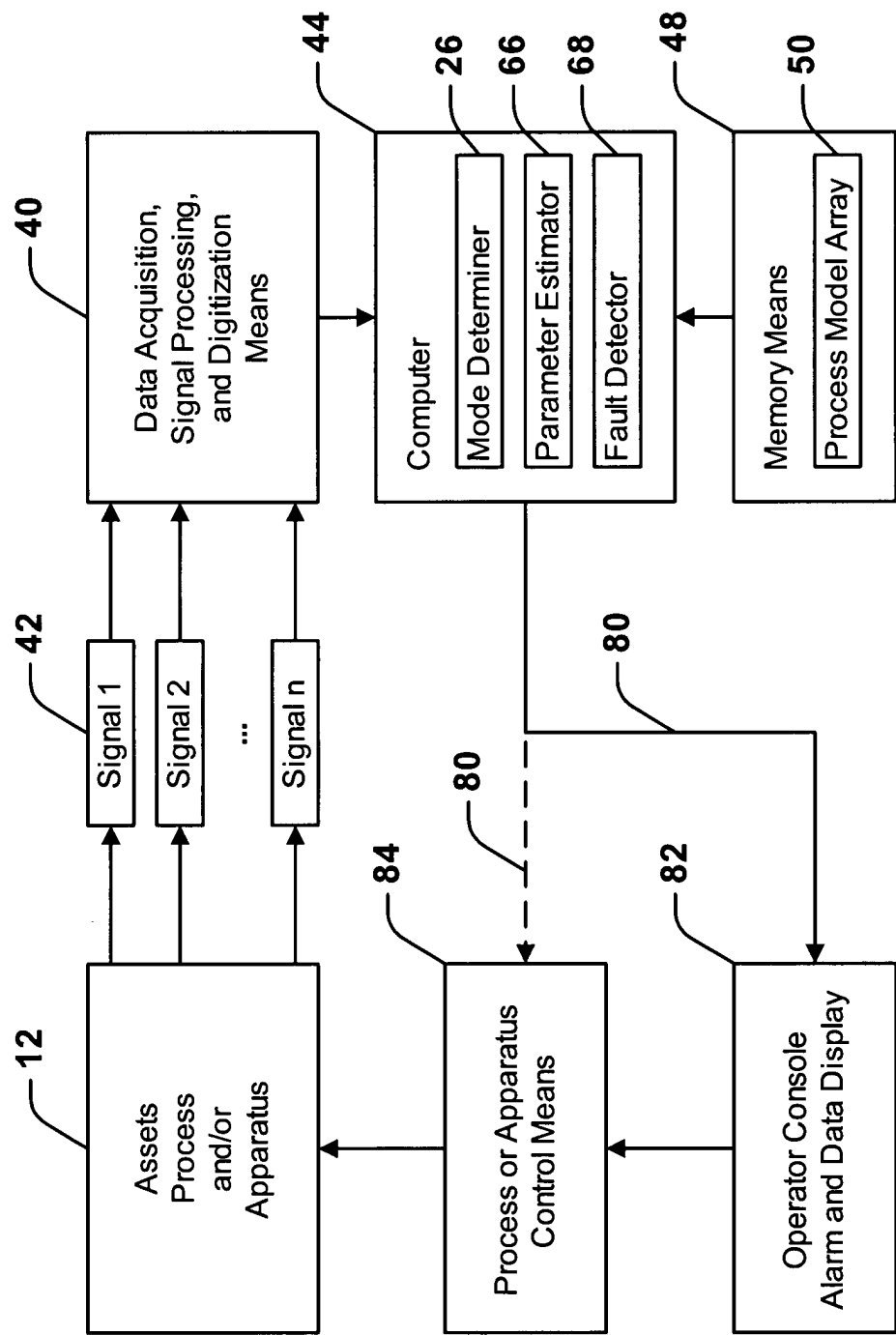


Figure 4

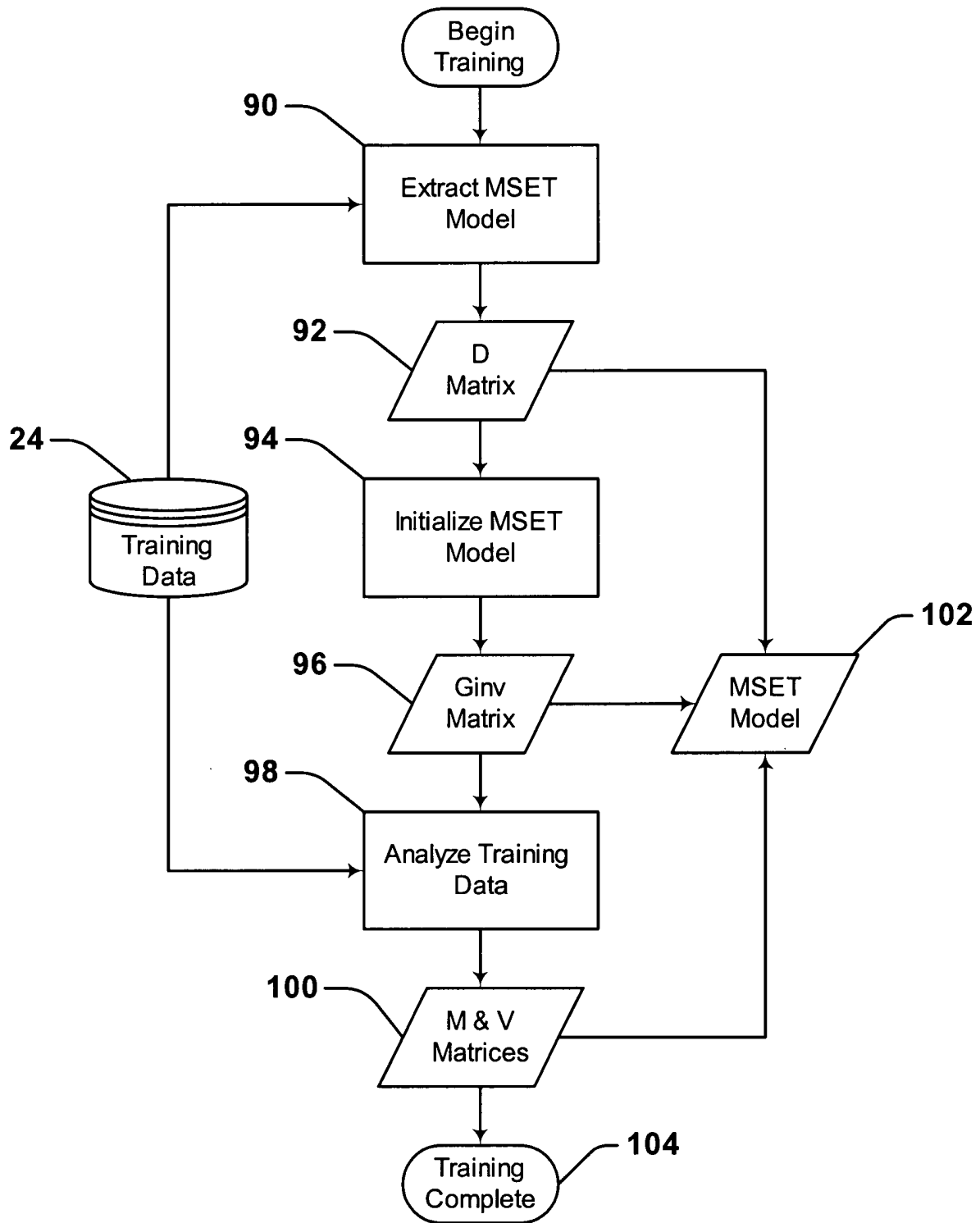


Figure 5

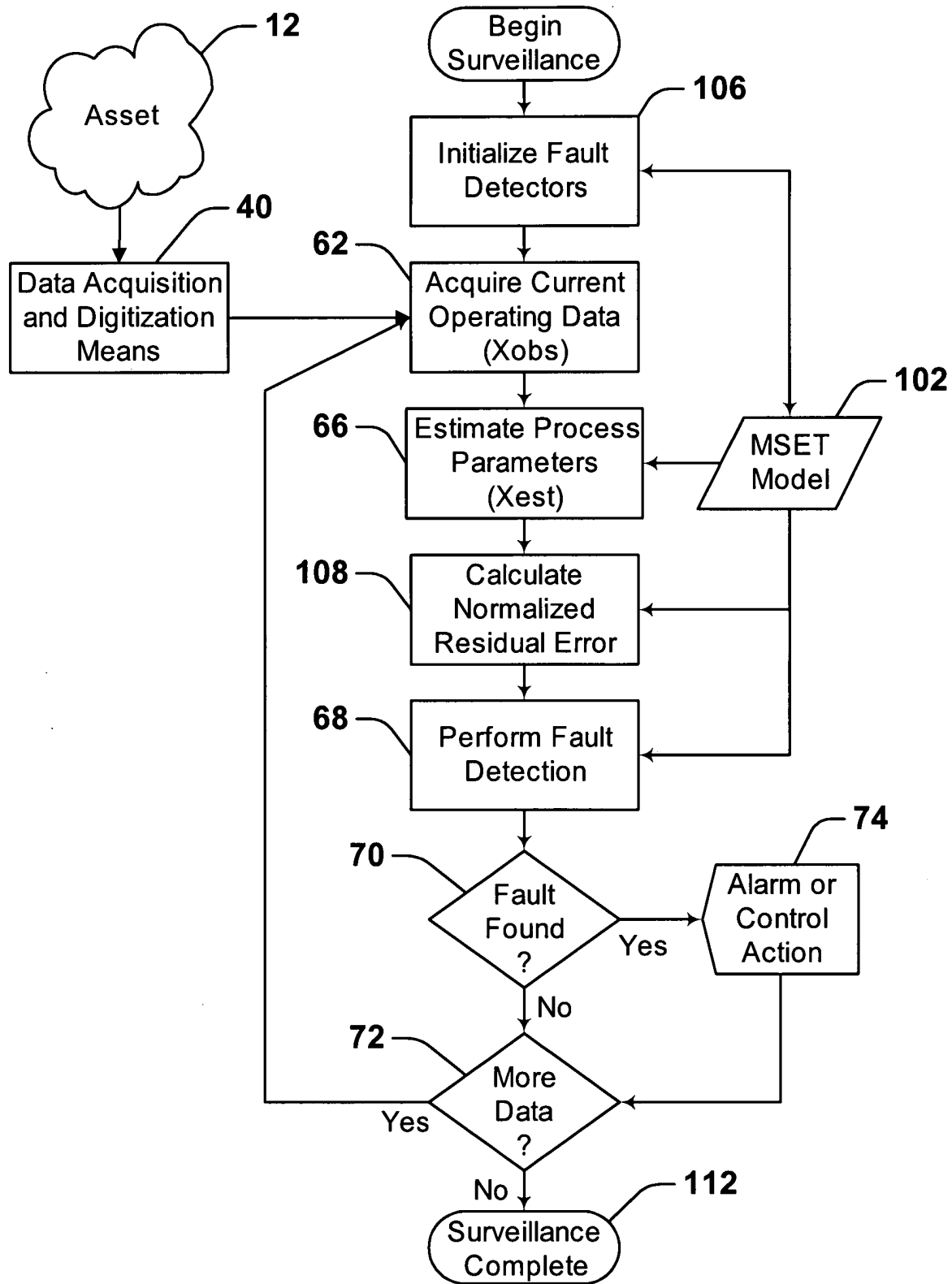


Figure 6

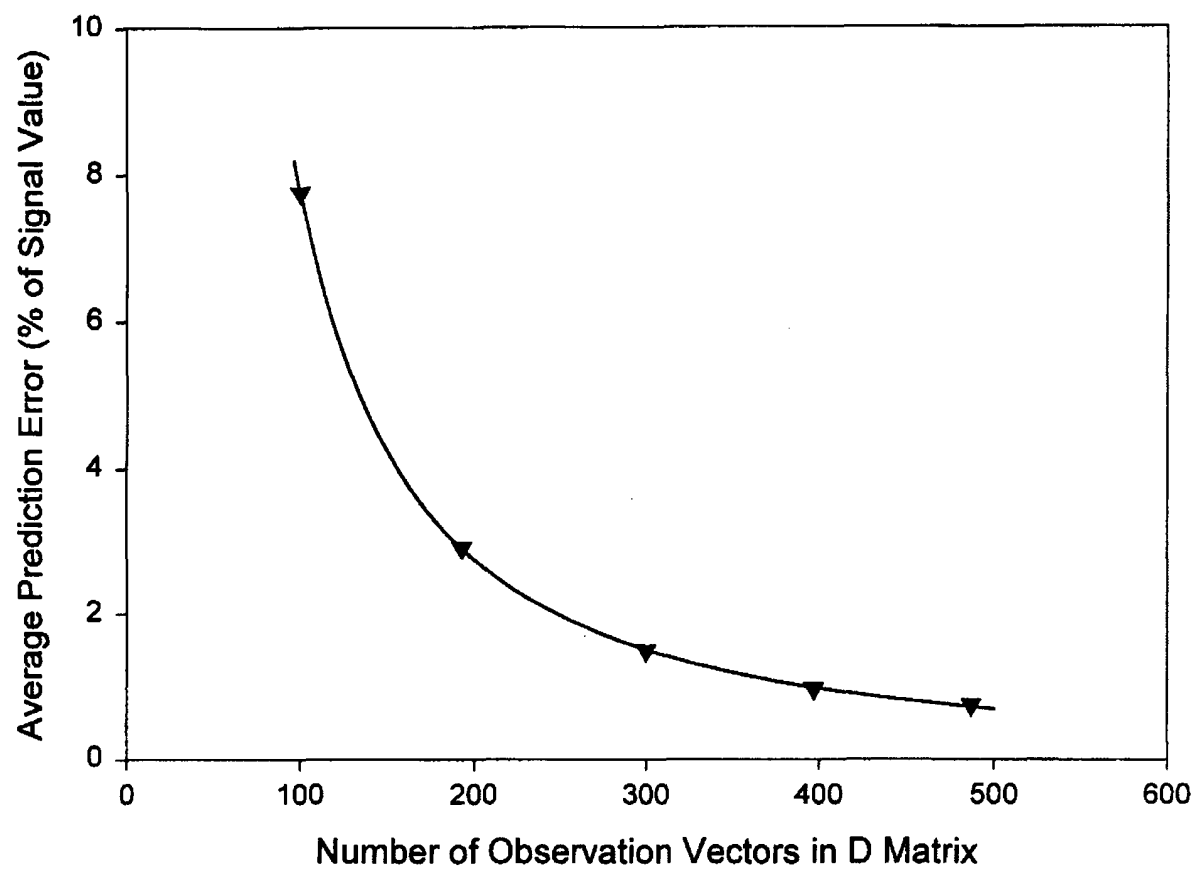


Figure 7

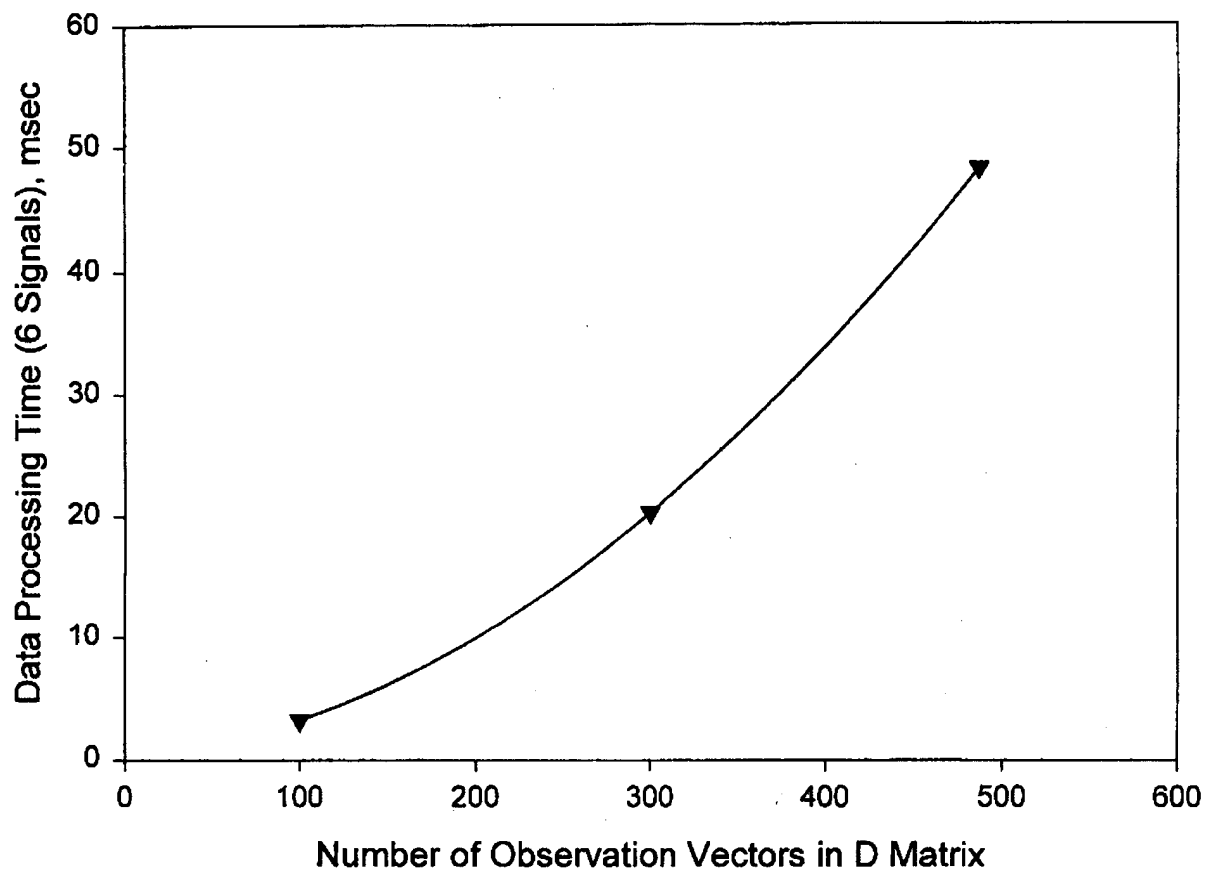


Figure 8



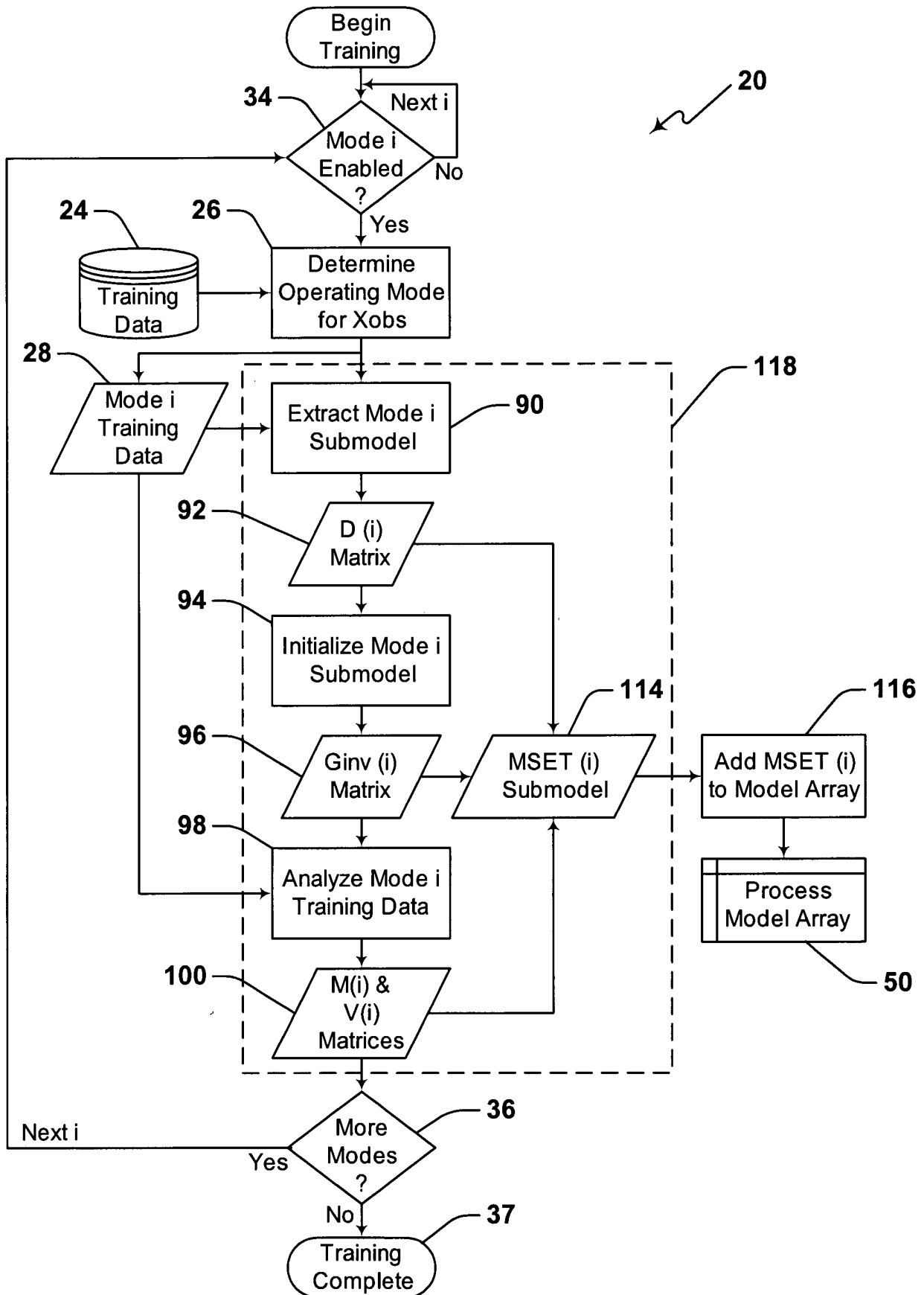


Figure 9

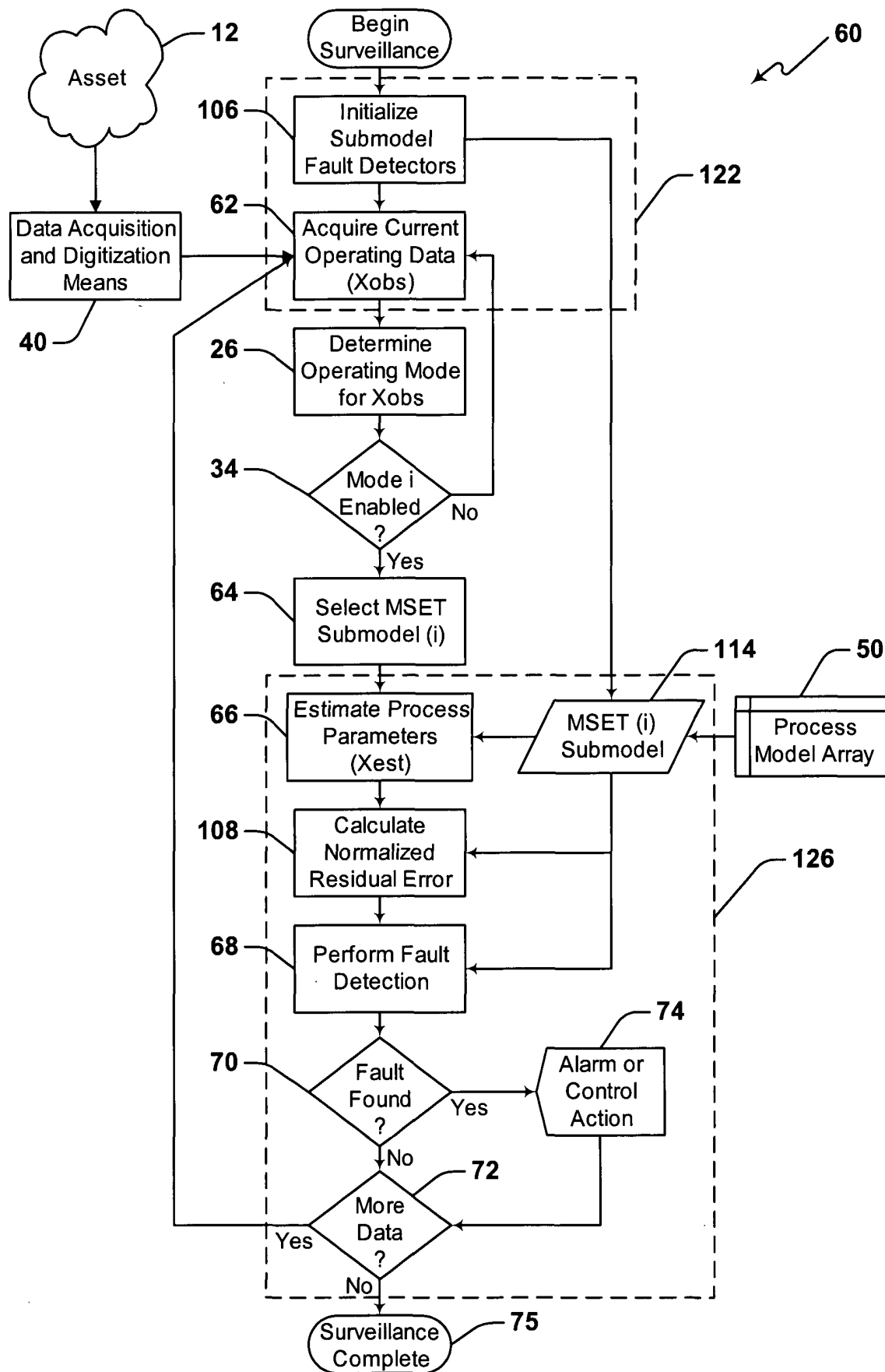


Figure 10

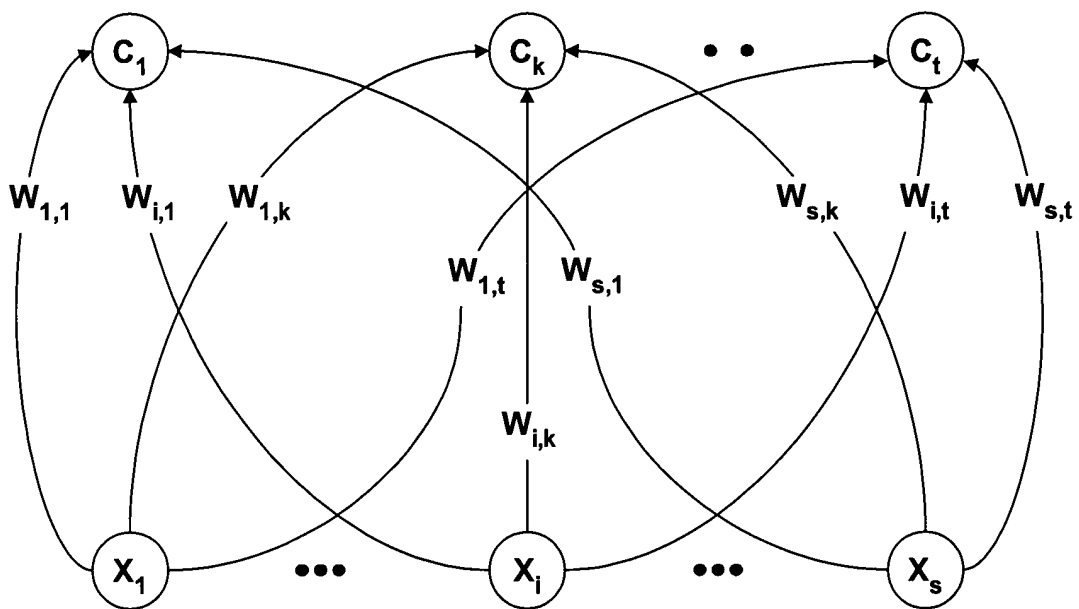


Figure 11

LVQ Neural Network Parameter	Design Value
Input Signals	MCC_PC_AVG (PC_CNTL_REF – MCC_PC_AVG) ( $\Delta$ PC_CNTL_REF / $\Delta$ TIME)
Number of Classes	9 (one for each operating mode defined in Figure 16)
Number of Output Nodes per Class ( $N_{\text{class}}$ )	8 (for each operating mode)
Learning Algorithm	LVQ2.1
Maximum Number of Epochs ( $n_{\text{eps}}$ )	250
Initial Value of the Learning Rate ( $\lambda_0$ )	0.02
Window Size ( $\epsilon$ )	0.5
Number of Training Vector Pairs ( $n_{\text{LVQ}}$ )	500

Figure 12

<b>SSME Signal Parameter ID</b>	<b>SSME Signal Parameter Name</b>
PID40	OPOV_ACT_POS_A
PID42	FPOV_ACT_POS_A
PID52	HPFP_DS_P_A
PID58	FPB_PC_A
PID63	MCC_PC_AVG
PID90	HPOP_DS_P
PID100	FUEL_FLOW_AVG
PID105	HPFT_DS_T_A2
PID106	HPFT_DS_T_A3
PID107	HPFT_DS_T_B2
PID108	HPFT_DS_T_B3
PID200	MCC_PC_A_AVG
PID201	MCC_PC_B_AVG
PID205	HPOT_DS_T_A2
PID206	HPOT_DS_T_A3
PID207	HPOT_DS_T_B2
PID208	HPOT_DS_T_B3

Figure 13

Space Shuttle Flight ID	Engine Position
STS077	E2
STS078	E1
STS081	E3
STS082	E1
STS085	E1
STS085	E2
STS086	E2
STS087	E2
STS087	E3
STS090	E1

Figure 14

<b>Model Description</b>	<b>Number of Signals</b>	<b>Modeled Operating Modes</b>	<b>Number of Process Mem Vectors</b>	<b>Parameter Estimation Method</b>	<b>Fault Detection Method</b>
LVQ mode-partitioned (Model PD)	17 (defined in Figure 13)	Start01 Start12 Start24 SteadyFull SteadyLow Upthrust Downthrust	150 150 150 150 150 150 150	MSET / SSA	SPRT mean pos & neg
All-modes (Model A150)	17 (same)	All	150	MSET / SSA	SPRT mean pos & neg
All-modes (Model A300)	17 (same)	All	300	MSET / SSA	SPRT mean pos & neg

Figure 15

Mode Name	Operating Mode Criteria
PREFIRE	All observations preceding the vehicle start command to the engine. Considered a non-operating mode.
START01	Controller cycles 0 through 24 after receipt of the engine start command.
START12	Controller cycles 25 through 49 after receipt of the engine start command.
START24	Controller cycle 50 through detection of steady-state operation (typically at controller cycle ~110). The rule for transition to STEADY_FULL is: If in START24 and if $ PC\_CNTL\_REF - MCC\_PC\_AVG  \leq (5 * 3.35)$ , and $PC\_CNTL\_REF \geq 2500$ transition to STEADY_FULL
STEADY_FULL	STEADY_FULL is declared when either: 1) the last cycle's state was STEADY_FULL and the commanded PC is both unchanged and greater than 2500 psi, e.g., $ PC\_CNTL\_REF - LAST\_PC\_CNTL\_REF  < 3.35$ and $PC\_CNTL\_REF \geq 2500$ ; or 2) when the last cycle's state was a transient state and $ PC\_CNTL\_REF - MCC\_PC\_AVG  \leq (5 * 3.35)$ and $PC\_CNTL\_REF \geq 2500$ .
STEADY_LOW	STEADY_LOW is declared when either: 1) the last cycle's state was STEADY_LOW and the commanded PC is both unchanged and less than 2500 psi, e.g., $ PC\_CNTL\_REF - LAST\_PC\_CNTL\_REF  < 3.35$ and $PC\_CNTL\_REF < 2500$ ; or 2) when the last cycle's state was a transient state and $ PC\_CNTL\_REF - MCC\_PC\_AVG  \leq (5 * 3.35)$ and $PC\_CNTL\_REF < 2500$ .
UPTHRUST	UPTHRUST is declared when 1) the commanded PC has increased since the last cycle, and 2) $ PC\_CNTL\_REF - MCC\_PC\_AVG  > (5 * 3.35)$
DOWNRHURST	DOWNRHURST is declared when 1) the commanded PC has decreased since the last cycle, and 2) $ PC\_CNTL\_REF - MCC\_PC\_AVG  > (5 * 3.35)$
SHUTDOWN	All observations following the vehicle shutdown command to the engine. Considered a non-operating mode.

Figure 16



Test No.	Test Description	Sensor Failures	One Cycle Alarms	Total Avg Error %	Avg Cycle Time
PD-01	STS077E1. Nominal flight data.	0	2	0.408%	4.88 msec
PD-02	STS077E2. Nominal flight data.	0	0	0.217%	4.90 msec
PD-03	STS078E1. Nominal flight data.	0	0	0.352%	4.98 msec
PD-04	STS078E2. Nominal flight data.	0	1	0.296%	4.94 msec
PD-05	STS081E1. Nominal flight data.	0	2	0.400%	5.01 msec
PD-06	STS081E3. Nominal flight data.	0	0	0.281%	5.07 msec
PD-07	STS082E2. Nominal flight data.	0	1	0.286%	4.96 msec
PD-08	STS085E3. Nominal flight data.	0	0	0.282%	4.98 msec
PD-09	STS086E2. Nominal flight data.	0	0	0.254%	5.02 msec
PD-10	STS087E2. Nominal flight data.	0	0	0.246%	5.02 msec
Average for All Tests		0	1	0.302%	4.98 msec

Figure 17

Test No.	Test Description	Sensor Failures	One Cycle Alarms	Time to Detect	Error at Detect
PD-11	Drift PID40. 0.14 pct/sec beginning at 10.0 sec.	1 (PID40)	5	28.88 sec	5.8%
PD-12	Noise PID40. ±5 pct random beginning at 10.0 sec.	1 (PID40)	38	10.76 sec	N/A
PD-13	Drift PID42. 0.16 pct/sec beginning at 10.0 sec.	1 (PID42)	9	29.32 sec	5.9%
PD-14	Noise PID42. ±5 pct random beginning at 10.0 sec.	1 (PID42)	66	42.04 sec	N/A
PD-15	Drift PID52. 11.9 psi/sec beginning at 10.0 sec.	1 (PID52)	4	12.24 sec	2.4%
PD-16	Drift PID58. 10.2 psi/sec beginning at 10.0 sec.	1 (PID58)	5	9.44 sec	1.9%
PD-17	Drift PID90. 8.2 psi/sec beginning at 10.0 sec.	1 (PID90)	9	8.12 sec	1.6%
PD-18	Drift PID100. 31.9 gpm/sec beginning at 10.0 sec.	1 (PID100)	5	12.12 sec	2.4%
PD-19	Drift PID105. 3.4 degR/sec beginning at 10.0 sec.	1 (PID105)	11	16.16 sec	3.2%
PD-20	Drift PID200. 6.3 psi/sec beginning at 10.0 sec.	1 (PID200)	4	3.40 sec	0.7%
PD-21	Drift PID205. 2.7 degR/sec beginning at 10.0 sec.	1 (PID205)	4	18.28 sec	3.7%
Average for All Drift Tests				15.3 sec	3.1%

Figure 18

Test No.	Test Description	Sensor Failures	On Cycle Alarms	Total Avg Error %	Avg Cycle Time
A150-01	STS077E1. Nominal flight data.	0	0	0.556%	5.27 msec
A150-02	STS077E2. Nominal flight data.	0	9	0.458%	5.28 msec
A150-03	STS078E1. Nominal flight data.	0	0	0.593%	4.90 msec
A150-04	STS078E2. Nominal flight data.	0	0	0.396%	5.28 msec
A150-05	STS081E1. Nominal flight data.	0	0	0.685%	4.67 msec
A150-06	STS081E3. Nominal flight data.	0	0	0.480%	4.77 msec
A150-07	STS082E2. Nominal flight data.	1 (PID58) False Alarm	13	0.720%	5.28 msec
A150-08	STS085E3. Nominal flight data.	0	0	0.519%	4.73 msec
A150-09	STS086E2. Nominal flight data.	0	0	0.410%	4.77 msec
A150-10	STS087E2. Nominal flight data.	0	0	0.399%	5.22 msec
Average for All Tests		0	2	0.522%	5.02 msec

Figure 19. Comparative Results

Test No.	Test Description	Sensor Failures	One Cycle Alarms	Time to Detect	Error at Detect
A150-11	Drift PID40. 0.14 pct/sec beginning at 10.0 sec.	1 (PID40)	19	125.68 sec	25.1%
A150-12	Noise PID40. ±5 pct random beginning at 10.0 sec.	1 (PID40)	12	95.04 sec	N/A
A150-13	Drift PID42. 0.16 pct/sec beginning at 10.0 sec.	1 (PID42)	12	154.92 sec	31.0%
A150-14	Noise PID42. ±5 pct random beginning at 10.0 sec.	0 (Missed Alarm)	0	Missed Alarm	N/A
A150-15	Drift PID52. 11.9 psi/sec beginning at 10.0 sec.	1 (PID52)	4	27.40 sec	5.5%
A150-16	Drift PID58. 10.2 psi/sec beginning at 10.0 sec.	1 (PID58)	6	18.92 sec	3.8%
A150-17	Drift PID90. 8.2 psi/sec beginning at 10.0 sec.	1 (PID90)	4	60.32 sec	12.1%
A150-18	Drift PID100. 31.9 gpm/sec beginning at 10.0 sec.	2 (PID100) & (PID58 False Alarm)	23	43.24 sec	8.6%
A150-19	Drift PID105. 3.4 degR/sec beginning at 10.0 sec.	1 (PID105)	10	46.20 sec	9.2%
A150-20	Drift PID200. 6.3 psi/sec beginning at 10.0 sec.	1 (PID200)	4	22.72 sec	4.5%
A150-21	Drift PID205. 2.7 degR/sec beginning at 10.0 sec.	1 (PID205)	8	89.04 sec	17.8%
Average for All Drift Tests				65.4 sec	13.1%

Figure 20. Comparative Results

Test No.	Test Description	Sensor Failures	One Cycle Alarms	Total Avg Error %	Avg Cycle Time
A300-01	STS077E1. Nominal flight data.	0	0	0.488%	17.84 msec
A300-02	STS077E2. Nominal flight data.	0	0	0.379%	17.75 msec
A300-03	STS078E1. Nominal flight data.	0	0	0.424%	19.40 msec
A300-04	STS078E2. Nominal flight data.	0	0	0.359%	19.02 msec
A300-05	STS081E1. Nominal flight data.	0	0	0.633%	17.69 msec
A300-06	STS081E3. Nominal flight data.	0	0	0.501%	17.80 msec
A300-07	STS082E2. Nominal flight data.	0	0	0.620%	19.01 msec
A300-08	STS085E3. Nominal flight data.	0	2	0.521%	17.73 msec
A300-09	STS086E2. Nominal flight data.	0	1	0.340%	17.78 msec
A300-10	STS087E2. Nominal flight data.	0	0	0.319%	18.10 msec
Average for All Tests		0	0	0.458%	18.21 msec

Figure 21. Comparative Results

Test No.	Test Description	Sensor Failures	One Cycle Alarms <sup>1</sup>	Time to Detect	Error at Detect
A300-11	Drift PID40. 0.14 pct/sec beginning at 10.0 sec.	1 (PID40)	39	138.80 sec	27.8%
A300-12	Noise PID40. ±5 pct random beginning at 10.0 sec.	0 (Missed Alarm)	2	Missed Alarm	N/A
A300-13	Drift PID42. 0.16 pct/sec beginning at 10.0 sec.	1 (PID42)	26	139.08 sec	27.8%
A300-14	Noise PID42. ±5 pct random beginning at 10.0 sec.	0 (Missed Alarm)	2	Missed Alarm	N/A
A300-15	Drift PID52. 11.9 psi/sec beginning at 10.0 sec.	1 (PID52)	9	26.04 sec	5.2%
A300-16	Drift PID58. 10.2 psi/sec beginning at 10.0 sec.	1 (PID58)	8	16.92 sec	3.4%
A300-17	Drift PID90. 8.2 psi/sec beginning at 10.0 sec.	1 (PID90)	6	58.12 sec	11.6%
A300-18	Drift PID100. 31.9 gpm/sec beginning at 10.0 sec.	1 (PID100)	9	23.36 sec	4.7%
A300-19	Drift PID105. 3.4 degR/sec beginning at 10.0 sec.	1 (PID105)	6	28.32 sec	5.7%
A300-20	Drift PID200. 6.3 psi/sec beginning at 10.0 sec.	1 (PID200)	6	18.52 sec	3.7%
A300-21	Drift PID205. 2.7 degR/sec beginning at 10.0 sec.	1 (PID205)	12	64.32 sec	12.9%
Average for All Drift Tests				57.1 sec	11.4%

Figure 22. Comparative Results

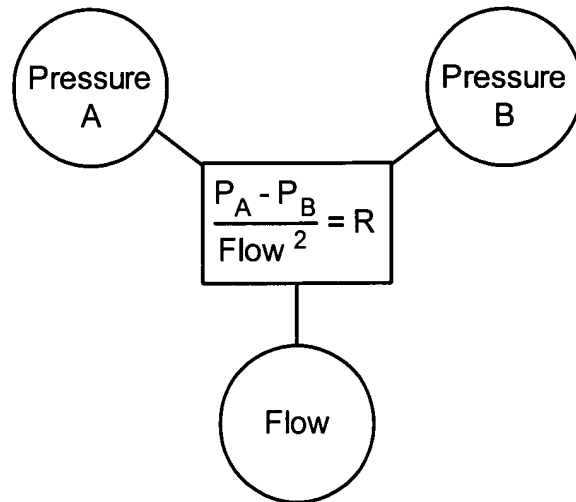


Figure 23